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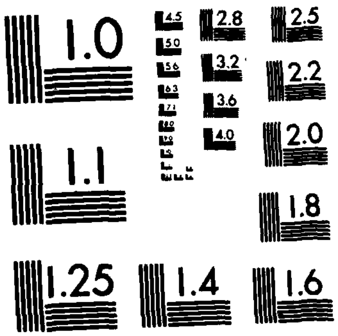

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by

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A MODEL FOR FORECASTING THE COUNTRY'S GENERAL USE DATA TRANSMISSION NETWORK

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The development of the information sciences in Poland and the concomitantly growing demand to data transmission services in the telecommunications network makes it necessary to search for an answer to the question of what effects data transmission will have on the development of the country's telecommunications network and what will be the technological and economic consequences of the various forecasts and assumptions concerning, e.g., the number of data transmission subscribers.

For the purpose of arriving at an answer to these and similar questions, work has been commenced in the Department of Telecommunication Networks of the Communications Institute on a method for forecasting development in the data transmission network. The magnitude of the problem, the great number of assumptions requiring testing, as well as the great number of possible variants that could be accepted -- all of these are the main factors decisive in the necessity for searching for solutions generated by means of computer programs. In this way, the notion has arisen of a computer-generated system for modeling the data transmission net [1]. The first version of this was a program block with the title TELEDACYA [Data-Transmission], written in FORTRAN 1900 and PLAN and run on an ODRA 1304 type machine. The second version, which

is a modified and expanded version of TELEDACYA, is the OSET block, written in FORTRAN IV and run on the R-32 computer. Both computer systems were generated with the cooperation of programmers from the Departmental Center for Electronic Data Processing in the Communications Institute.

In developing working hypotheses and assumptions, the information that was used is based on the methods for forecasting developments in the already existing secondary telecommunication networks, and especially in the telephone network, taking into account the specifics of data transmission, and particularly, the differences between data transmission terminals with respect to transmission rates used.

In the process of forming a model for forecasting for a net to cover the whole country, we are involved with drawing a picture with completely new qualities. This makes it necessary to accept a whole series of base assumptions that have an arbitrary character, for there are no empirical bases upon which it will be possible to base their formulations. All the same, model researches involving the construction of variant models using variations in particular assumptions and hypotheses and the description of the effects of these variations on the form of the model take on general significance.

For the sake of simplicity, an inter-urban, synchronous data transmission net will be considered here involving customers for the data transmission with rates exceeding 600 bits/sec.

Given below are the general characteristics of the system of computer programs used for modeling, and particular assumptions accepted for constructing the model will be presented, as well as two applied models for the data transmission net; particular and general conclusions have also been drawn.

General characteristics of the computer program system

The modeling system for the data transmission net was developed keeping in mind that this is the first attempt of its kind in our country to take up this problem, that knowledge of the present state of affairs concerning studies and researches carried out throughout the world is incomplete, and that in many countries the formulation and construction of a data transmission net continually introduce new solutions. In connection with this, in developing hypotheses and assumptions for systems studied, we have been directed by principles of their maximum simplicity, accepting at the same time a series of restrictions concerning, e.g., the extent of the area involved in the modeling problem (restricting to an inter-provincial network). These restrictions were necessary in order to generate concrete results within the shortest possible time. In connection with this, particular attention was paid to assuring maximum system flexibility. We may mention the following elements, in particular, which assure this flexibility:

- modular structure of the system, i.e., developing it as a set of programs, each of which may be replaced by another program;

- feasibilities for controlling a sequence of processing individual programs, which has significance, e.g., for the construction of optimization loops;

- the application of so-called switches, assuring variation in certain program fragments;

- handling possibly large numbers of magnitudes as input data.

In the TELEDACYA system, the range of work was limited to problems of an analytical nature, i.e., the description of basic indicators defining a net for a given net structure. In developing the OSET system, the problem of synthesis was also taken into consideration, i.e., the assignment of a net structure that would be characterized by the most

economical system of cost indicators and quality indicators in fulfilling certain restrictions holding for that net. At the present state of researches, only inter-exchange communications networks have been optimized, using a determined number and distribution of switching exchanges. From experience gained in this area, it turns out that this kind of optimization -- possible with computation capabilities connected with having an electronic computer -- can be carried out only for an uncompensated net. Another direction that would come about as a consequence of extending the range of problems contained in the programs would have to do with including a lower layer net in our considerations, i.e., regional nets, and involving considerations of the problem of concentrator distribution in that net. The solution to this problem requires, however, hypotheses and assumptions concerning the nature and mutual relationships between concentrator costs and link costs at this net layer and must be based on further studies.

The process of network modeling carried out by means of successive computer programs can be represented in the following manner: given is a set of junctions described by their geographical locations as well as weightings defining their magnitudes. Each junction is treated as a traffic generator with a certain average value expressed as the number of bits flowing through the net for the period of one second. The difference in this traffic between individual relationhips describes the generation model accepted and traffic propagation. In agreement with this model -- establishing communications traffic generated in a net -- a matrix of important inter-junction traffic characteristics is described, whose elements (i, j) describe information flow from junction i to junction j.

In the set of junctions, the subset of main, privileged junctions with respect to weightings or their central positions within the net is distinguished. The complement to this set is the subset of subordinate junctions. An ordering is introduced in which for each subordinate junction there is one and only one main junction. This ordering is assigned in the process of net decomposition. A main junction together with the subordinate junctions assigned to forms a so-called region.

The topological structure of the net is represented by a diagram described by a set of junctions and inter-junction branches connecting them (data transmission links[1]).

According to the hypotheses and assumptions accepted, a subordinate junction is connected by means of only a single branch with a corresponding main junction, and in addition, a main junction can be connected with many (in the extreme case, with all) main junctions. The information flow path within the network between each pair of junctions is according to principles of traffic flow, according to which the shortest path with a minimum number of intermediate junctions is chosen. The determination of these tracks made it possible to compute the magnitudes of traffic flow through individual branches and junctions.

On this basis, and taking determined transmission quality parameters into consideration which depend on the type of switching (e.g., average message delay in message switching or a traffic loss factor during communications switching), flow capacities of individual network branches as well as their relative costs were established. In the last phase of computations, overall values for the whole network were determined and its quality and cost factors were determined.

In the OSET system, two essentially new elements were introduced, in contrast to the TELEDACYA system. For the first time, the diagrams of the connections between main junctions were studied from the point of view of the determined conditions for structural reliability (taking an appropriate number of independent pathways between arbitrary pairs of junctions on the graph). Diagrams not fulfilling these conditions are excluded. Secondly, in accordance with the assumptions given at the beginning, a certain time optimization is introduced which depends on the selection of the structure of the network of links with a given

[1]By "inter-junction data transmission link," we understand the entirety of means serving for the transmission of data between a given pair of junctions, regardless of their technical realizations (these kinds of links may be carried out by means of digital or analog technology and may use multiplexing, either frequency or time division multiplexing).

junction distribution. In the process of processing those kinds of configurations for the network of links are sought which will assure the lowest costs for constructing a net with the best quality indicators (in the TELEDACYA system, the diagram of junction links is imposed from above).

The input data used in the system of successive programs can be divided into the following groups:

- information concerning the junctions (geographical coordinates as well as weightings);

- conditions imposed on the topological structure of the net (the hierarchy of junctions and their possible connections, the graph of the connecting network between main junctions);

- the parameters of traffic generation and parameters of the model of traffic propagation (e.g., the number of subscribers and their distinction according to category, the division of traffic into internal and inter-regional);

- parameters controlling the selection of a pathway;

- quality parameters -- depending on the kind of switching;

- the factor used in computing link and junction costs;

- possible factors determining the margins of branch flow capacity;

- possible reliability conditions.

The output data (results of calculations) include comprehensive parameters for the entire net (assumed or partially optimized), with a breakdown into levels emerging from the hierarchical structure of the net, as well as the parameters having to do with individual branches

and junctions. These are foremost:

- traffic flow in the net and in its elements (junctions and branches);
- flow capacities expressed as the number of conventional primary pathways (if necessary, with a breakdown into individual subscriber categories);
- determined quality indicators;
- costs in relative units.

In this way, it is thus possible to have a readout of all other information generated in the individual modeling phases contained in the so-called data base.

Base modeling assumptions

The following working assumptions were taken for studies of a data transmission net presented in the present article [2]:

1. In some agreed forecasted year (e.g., the year 2000) the overall number of terminals connected into the data transmission net will be 78,500.

2. It has been accepted for simplicity's sake that the terminals connected into the data transmission net are divided into only two groups: the first numbers 78,000 (this is a type t with average transmission rate from 600 to 9600 bit/sec) and a second group numbering 500 (type T with great transmission rates, 48 kbit/sec).

3. The traffic flow generated (in the GNR [expansion unknown]) through terminals with average bit rates is on the average 0.1 E [erlangs], and through large bit rate terminals it is on the average 0.25 E.

4. On the geographical territory containing the modeled net, the spatial distribution of terminals corresponds to the spatial distribution of telex instruments for the same territory.

5. The overall data transmission traffic generated through the terminals is divided into intra-regional and inter-regional traffic, with values, respectively, of 0.6 and 0.1, while we take the notion of "region" to be that territory served by a single inter-urban switching center.

6. The flow of traffic features interesting from the point of view of data transmission is based on a model of uniform traffic propagation, i.e., the flux of interesting traffic features from the point of view of data transmission will be proportional to the products of the numbers of terminals grouped together in two territories under consideration, and in addition, this flux will not be dependent on distances between these territories.

7. The data transmission network will be a three-layer one (Fig. 1). The highest layer will be the set of inter-urban switching junctions W, the intermediate layer will be the set of concentrator junctions K, and the set of t and T terminals will be found on the lowest layer., as well as the data transmission equipment (e.g., multiplexers, M).

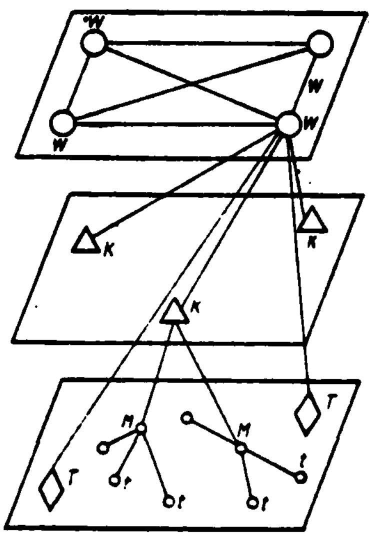

Fig. 1. Data transmission net hierarchy.

8. Only two end-to-end computer communications links with a determined maximum number of intermediate elements can occur in the data transmission network:

- according to Fig. 2a, for connections between two average transmission rate terminals;

- according to Fig. 2b, for connections between two high bit rate transmission terminals.

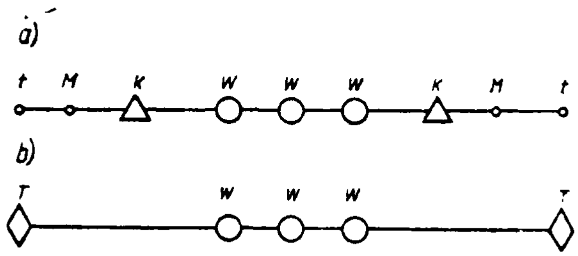

Fig. 2. Basic structures of connections within the data transmission network: (a) end-to-end connections between terminals of the average bit rate type t; (b) end-to-end connections between terminals of the high bit rate type T.

9. The data transmission net will have a hierarchical structure, i.e., one such that a determined number of t terminals will be connected with a concentrator K over them, and that a determined group of concentrator junctions will be connected with a switching center W over it. It has been accepted, in addition, that a determined group of T terminals will be directly connected with a switching center over them. The network of switching centers will be connected up in such a way by means of transmission links that transmission from one switching junction to another will be carried out either across a direct link or (in the case of an emergency on that link) by means of a highest single intermediate junction. Thus, the switching centers will be connected by means of line trunks in a complete polygon system.

10. Line switching will be carried out in the switching junction level and the concentrator junction level.

11. It has been assumed that the locations of the switching centers are concrete. In the example presented here of forecasting, each of

the hypothetical switching junctions in the data transmission net is located at a central point of one of the 12 regions into which the entire extent of the network has been divided, each of the regions being congruent and overlapping with the service areas for those junctions numbered successively from 1 to 12.

12. It has been assumed that there are concrete locations for the concentrator junctions, namely at central points (cities) within the subregions (the territories making up the regions).

13. It has been accepted that a single concentrator can hook up 500 medium bit rate terminals (2400 bit/sec) at the maximum.

14. The concentrator junctions will be hooked together with switching junctions by means of concentrator links using wideband channels[2].

15. Rapid bit rate terminals are connected with subscriber switching junctions by means of computer links employing wideband channels with flow capacities of 48 kbit/sec.

16. One of the means for assuring sustained and continuous computer communication flow in the line groups and lines is setting up certain reserves and margins such as the following.

- in subscriber computer links (between type T terminals and a switching center) -- one additional wideband channel;

- in concentrator links (between a concentrator junction and a switching center) -- three wideband channels for each concentrator:

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[2]Taking as a basis average magnitudes of traffic and information flow produced through the terminals of the t type (according to assumption No. 3), and taking into account also the number of terminals hooked up to a concentrator junction, and assuming traffic losses to be at the level of 1‰, it is possible to determine an initial estimate of the number of channels with flow capacities of 2400 bit/sec in a link group. This amounts to 120, which corresponds to six wideband channels with flow capacities of 48 kbit/sec (a primary group in a telephone multiplex system).

- in main trunk line groups (between switching centers) -- 10% of the extent of the line trunk expressed as the number of primary groups with rounding off upwards.

It is necessary to mention a certain problem before presenting the synthetic results of the computer modeling, i.e., it is necessary to explain how the results presented here from computations can be translated into concrete forecasting reality, or to what degree we may draw conclusions on the basis of these results concerning a data transmission net to be built in Poland. Thus, we have the following considerations:

• The total number of data communication terminals taken at the beginning (cf. assumption 1) has been taken from forecasting data concerning the expected development of telecommunications in Poland [3].

• The model for the spatial distribution of terminals has been determined analogously from the expected distribution of teletype equipment in the teletype network (cf. assumption 4).

• The telecommunications switching centers have been located in the more important provincial cities (cf. assumption 11), taking the main criterion to be their present location or the planned creation of other telecommunications junctions in these cities within a certain time period.

• Regions covering 3-6 provinces have been taken as the service areas for central exchange junctions, taking the criterion to be the economic and administrative interrelationships between the provinces of a single region.

The adoption of the above assumptions will help bring the model under study into actuality; however the credibility and reliability of these assumptions and the model depend mainly on the following:

- the reliability of the accepted numerical forecast data;

- the precision of assumptions and hypotheses concerning the distribution of terminals, the model of traffic factors, and on the value of traffic generated through the terminals in the different categories, etc.;

- on the precision in the qualitative data established concerning net hierarchy, the positioning, and the number of switching centers, the switching system, and the kind of basic links.

Having said all this, the modeling results can still only be treated as a rough estimation of the scale of the size of any future data transmission network for the country (under the determined numerical assumptions and hypotheses) and of its technical and structural features within the range of a certain, delimited qualitative variant. We must also take account of the fact that the choice of variant depends on the range of necessarily direct technical or economic factors. On the other hand, the possibilities of coming up with different variants within the model by changing individual or specific assumptions and hypotheses, both numerical as well as qualitative, creates the possibility for comparison, and in this way, may lead to justifications for the selection of the best possible variants.

Basic results from the model studies

In Table 1 the numerical data illustrating the most important quantitative assumptions and hypotheses are tabulated, including the numbers of t and T terminals assumed for the individual regions numbered from 1 to 12, as well as the prognostication and forecasting data for an interurban data transmission network determined for them. These prognostication data include the following:

- the number of concentrators;

- information flow capacities of input and inter-junction trunks;

- central junction capacities.

Table 1. Tabulation of more important base data and results of the modeling.

Region	Number of terminals		Number of concen-trators	Size of input trunks*	Size of inter-junction trunks		Central junction capacities**	
	Type t	Type T			Unoptimized variant	Optimized variant	Unoptimized variant	Optimized variant
1	2	3	4	5	6	7	8	9
1	2910	19	6	45	79	48	1550	1100
2	1800	25	10	67	88	77	2100	1950
3	8370	53	20	140	123	104	3900	3600
4	11710	75	23	161	143	178	4850	5050
5	6000	38	14	125	106	66	2850	2400
6	2850	19	7	41	77	41	1600	1250
7	4810	31	12	67	98	155	2500	2950
8	8510	54	20	165	125	171	3050	4250
9	3010	16	8	65	84	43	1800	1350
10	6110	39	14	86	106	65	4100	3600
11	13600	86	30	122	157	189	5450	5850
12	6100	41	14	120	106	65	2900	2400
Total	78000	490	180	1225	1298	1196	37650	35750

*) Expressed in number of primary groups
**) Expressed in number of 2400 bit/sec balanced line terminations

The trunk flow capacity and the central junction capacity are given separately for an unoptimized variant (an inter-junction net in a closed polygon system) and an optimized variant.

As may be seen from this tabulation, the net is characterized by a considerable number of concentrators, i.e., up to 180. This is mainly a result of the assumption that 500 medium bit rate terminals are hooked up to a single concentrator (cf. assumption 13). From the overall number of terminals, it should turn out that there is a need for 78,000÷500 = 156 concentrators. The excess of 24 results from the fact that a number of terminals in the individual provinces is not a whole multiple of 500. This 15% excess may be considered, on the other hand, a reasonable operational margin. It must also be taken into consideration here that not all concentrators will enter into the composition of the inter-urban net. A considerable portion of them, which may be estimated to be about 30 to 40%, will function in the urban concentrator nets. This concerns especially those that will be constructed in the immediate vicinity of central exchange junctions. It is not possible to carry out a more thoroughgoing estimation, for this would require assumptions concerning the actual and concrete localizations within the cities of the lower provincial layer (cf. assumption 12).

The sizes of trunks for input links (from the concentrator to a central exchange junction) placed in column 4 in Table 1 have only to do with inter-provincial connections within the limit of each of the regions, and thus those that are certain to be part of the inter-urban network. It is probable that the overall number of input links would be somewhat greater than that presented in the tabulation; however, with respect to what was explained above, it is not possible to determine them in any greater detail, because a portion of the input links between the concentrators placed in the neighborhood of central exchange junctions and those junctions can also be a part of the inter-urban net.

Comparing the summary magnitudes for inputtrunks and inter-junction trunks, it is possible to see their apparent agreement. Actually, however,

taking into account that the numbers given in columns 5 and 6 include all links entering and leaving from each of the junctions, their sums include each trunk two times. From this, the total for a trunk, or for a conventional cable whose size is described as a sum of the size of the cables between all pairs of directly connected junctions is in both cases half the number given in columns 5 and 6, amounting, respectively, to 649 and 597 primary groups.

A better measure of the size of the net, taking into account not only the size of the trunks, but also the distances between junctions, is the overall length of the links used in the net. In the input line net, the total length of the links (primary group links) is 207,274 km, and in the inter-urban link net it is 193,522 km in the first variation and 126,780 km in the optimized variation. For the entire inter-urban net, the unoptimized variant is characterized by a length of 400,756 km, whereas the optimized variant by 334,014 km. As may be seen, as a result of optimization, the overall length of links in the inter-urban network is reduced by about 20%, and the diagram of the net is subject to a considerable simplification as a result of decreasing the number of direct connections. At the inter-junction level, savings are up to 35%.

Table 2 together with the schematic mappings shown in Fig. 3 may serve as an illustration of the form of the net in the first and optimized variations. The data presented in Table 2 have to do with trunk sizes in the individual connections. The area below the cross-hatched boxes has to do with the first variant, and the area above the cross-hatched boxes with the optimized variant.

In the first variant there are 66 direct connections. The average size of a cable is 9.83 primary groups (196.6 channels with flow capacity of 2400 bit/sec). As a result of optimization, there followed a reduction in the number of direct connections to 30, and the average size increased to 19.9 primary groups (398 channels). There followed as well a shift in the most heavily loaded cables.

Table 2. Inter-junction trunk links shown in terms of numbers of primary groups.

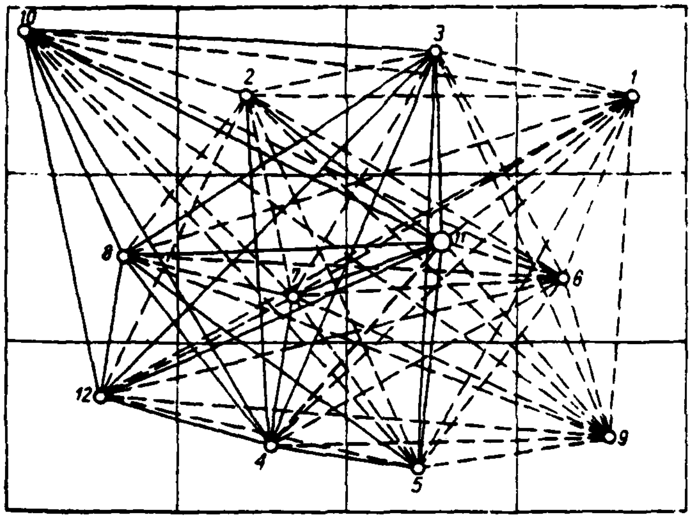
	1	2	3	4	5	6	7	8	9	10	11	12
1			10	9							21	
2	7		9				15	11		18	24	
3	7	9					27	20		14	24	
4	9	11	17		28	14	27	38	17		24	21
5	7	7	11	14			29		9			
6	5	6	7	9	7		11				16	
7	7	7	9	11	9	7		21			25	
8	8	9	14	17	11	7	10			33	21	27
9	6	7	9	9	7	6	7	9			17	
10	7	7	11	14	9	7	9	11	7			
11	9	11	18	24	15	9	13	18	10	15		17
12	7	7	11	14	9	7	9	11	7	9	15	

In the first variant the largest trunk (24 primary groups) figured in the 4-11 connection, whereas in the optimized variation, in the 4-8 connection. From optimizing the net, the number of small trunks (lower than 10 primary groups) has been lowered. In the first variant they were 64%.

The tabulation of necessary central exchange capacities given in columns 8 and 9 is interesting. These capacities were expressed in a number of balanced 2400 bit/sec line termination links. Taking into consideration that there are also 48 kbit/sec links connected to the central exchange junctions, the appropriate factor taken to be used in the conversions is that one 48 kbit/sec line termination link equals 2.3 2400 bit/sec line terminations. This factor has been determined on the basis of comparisons to be an approximate average value for several types of electronic data transmission centrals using the principle of delay switching.

As may be seen from the numbers presented in the tabulation, the overall number of line terminals in the central exchange junctions, which

a)



b)

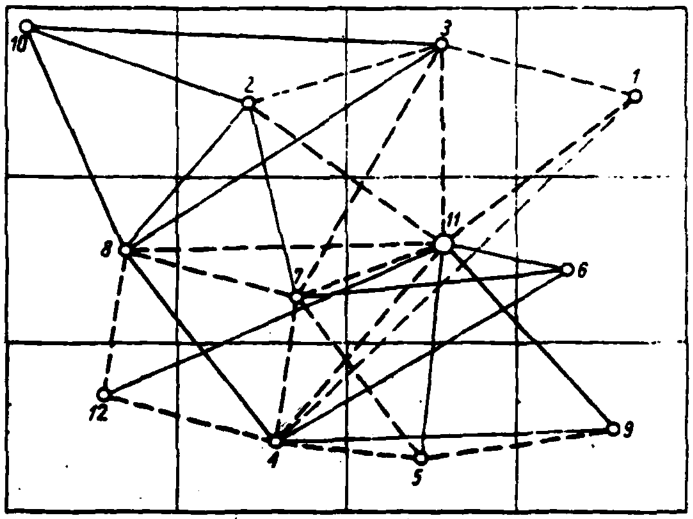


Fig. 3. Link structure in the inter-junction data transmission net: (a) the first variant - complete polygon, (b) the second variant, optimized polygon.

------- trunks for 9 primary groups

——— trunks for 10-19 primary groups

------- trunks for 20-29 primary groups

——— trunks for 30-39 primary groups

amount to 37,650 in the first variant, is reduced by 1900 in the optimized variation, i.e., by about 5%. This is the effect of traffic concentration. It is possible to see, as well, that as a result of optimization, small centrals have been reduced, and the largest ones have increased. In the first variant the ratio of the traffic-carrying capacities of the largest and the smallest central is 3.65, and in the optimized variant it is 5.32.

Conclusions

The stipulations on how it is possible to proceed with regard to the individual base assumptions and hypotheses of the modeling, as well as the conditions presented above on the reliability of a forecast model for a data transmission network do not detract from the appropriateness of developing and using in a practical manner computer modeling methods for computer communications networks. The results obtained up to the present time, a portion of which has already been presented here, could be termed characteristic for the country's future, general-use data transmission network only with difficulty. On the other hand, they give a good illustration of the scale and technical and economic consequences of such an undertaking as constructing this kind of net. In setting up appropriate cost indicators, it would also be possible to make attempts at estimating the necessary financial outlays for this purpose. It must also be realized that a change in the individaul assumptions and hypotheses, especially in those concerning the choice of switching system, kinds of basic links, or on the other hand, the assumption of a different net hierarchy or a different number and different placements of the switching center, can radically change the cost estimations.

It is possible to conclude, however, that in any case a sum on the order of several tens of billions of zlotys must be taken into consideration. It is understandable that with such large outlays special significance is attached to possibilities for departing from "expert" methods in the process of building a concept for a future network, departures

such as chances for the rationalization and objectivization of processes in forecast and prognostication planning. Of particular worth is not only the acquired possibility of carrying out accurate calculations in an area where this would be difficult or even impossible to do without the use of electronic computer techniques, but also the possibility of a relatively easy and rapid construction of a model of variants, and the possibility for studying technical consequences, and especially economic consequences of the a priori given assumptions and hypotheses.

As a consequence, computer modeling for a network can serve for the optimization of decisions undertaken in the planning processes, development programming, and network construction. In the same way, the need for continuing work on the development of equipment and facilities serving this purpose is unarguable. The OSET system, which is a substantial step forward as concerns the TELEDACYA system, must be developed further, especially in the direction of increasing its optimization possibilities. The optimization procedure, as presented in the OSET system, is at the present time still quite primitive, being restricted to minimizing network link costs without taking into consideration the junctions within the network. Reducing the overall central exchange junction traffic capacities is in no way an accidental product of the procedure as applied.

Parallel studies should be carried out to define and correct certain initial assumptions which were made in modeling the network. In particular, this applies to the assumed model of traffic interests and the adopted division of traffic into intraregional and interregional (cf. assumptions 5 and 6). At the same time work should be undertaken on optimization of the network in the input layer.

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